Paper VI

Unidirectional SAW transducer for gigahertz frequencies

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VI

Letters

Unidirectional SAW Transducer for Gigahertz Frequencies

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***Abstract*—A single-phase unidirectional transducer (SPUDT) structure using $\lambda/4$ and wider electrodes is introduced. The considerable difference between the reflectivity of short-circuited $\lambda/4$ electrodes and that of floating $\lambda/2$-wide electrodes on 128° lithium niobate ($LiNbO_3$) is exploited. The surface acoustic wave (SAW) device operating at 2.45 GHz has critical dimensions of about 0.4 μm, accessible for standard optical lithography.**

I. INTRODUCTION

Modern wireless communications systems operating above 1 GHz require increasingly enhanced performance from the passive components used for signal processing. The demands for filter characteristics typically include low insertion loss, low passband ripple, a high degree of linearity of phase, and high selectivity. A frequently used approach uses single-phase unidirectional transducers (SPUDTs) [1], [2]. The SPUDT devices also are attractive for SAW sensors and tags.

The majority of approaches reported until now use $\lambda/8$ or narrower electrodes or gaps [3]–[5]. For these schemes, in the gigahertz range the critical dimensions are beyond the limits of feasibility of current large-scale fabrication techniques. For tags operating at 2.45 GHz, another problem arises from the need for a wide aperture that, together with narrow electrodes, yields unacceptably high resistive losses. To achieve larger critical dimensions, various grouping schemes of electrodes and/or operation at harmonic frequencies [6]–[9] have been proposed. To date, nevertheless, SPUDT transducers are seldom used above 1 GHz. Attempts to find SPUDT structures based on $\lambda/4$ or wider electrodes have been made, e.g., in [10].

In this letter, a SPUDT structure based on recent research results for gratings on 128° lithium niobate ($LiNbO_3$) is proposed. In the previous work [11], [12], a considerable difference between the reflectivities of a short fundamental-mode reflector and that of a grating operating at the second-harmonic mode was demonstrated, a feature advantageous for SPUDT design [1]. Because only $\lambda/4$- and $\lambda/2$-wide fingers are used, the proposed geometry is feasible for gigahertz-range frequencies. In addition, floating electrodes serve to minimize resistive losses.

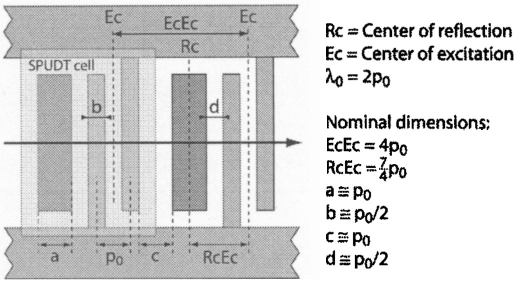

Fig. 1. Parameters of a SPUDT element.

II. SPUDT STRUCTURE

The operation principle of a SPUDT structure demands superimposing the reflectors and transducers in such a way that, within each unit cell, the center of transduction is shifted with respect to the center of reflection [1], [2]. Ideally, this phase shift should be $\pm\pi/2$. In most of the currently used SPUDT structures, $\lambda/8$-wide electrodes are applied for achieving nonreflecting transduction and, as the reflectors, $\lambda - 4$- or $3\lambda/8$-wide electrodes are implemented.

Contrary to the approaches mentioned above, we make use of the fact that $\lambda/4$-wide electrodes on 128° $LiNbO_3$ are weakly reflecting for metal thicknesses 1–6% of h/λ. Moreover, for each particular thickness, a metallization ratio (a/p) corresponding to vanishing reflectivity of the fingers can be found. For example, in a short-circuited long grating, the reflection coefficient for $a/p = 0.5$ is close to zero for the reflective aluminum thickness 2.5%. For a single $\lambda/2$-wide floating electrode, the reflection coefficient was found to be significantly higher [11], [12]. The main idea of the SPUDT design presented here is the use of these above-described structures as transducers and reflectors.

The topology for the proposed unidirectional transducer is illustrated in Fig. 1. One SPUDT cell is nominally $2\lambda_0 = 4p_0$ wide, and it consists of a strongly reflecting $\lambda/2$-wide floating electrode and a weakly reflecting pair of $\lambda/4$-wide fingers for excitation. The center of reflection (Rc) is approximately at the center of the wide floating electrode, and the center of excitation (Ec) is at the center of the gap between the $\lambda/4$-wide electrodes. The forward direction in Fig. 1 is to the right. Simple comparison of the generated and reflected forward-propagating waves (completely ignoring the reflectivity of the $\lambda/4$-wide fingers), within one cell, shows that the phase difference equals 4π, and thus the waves interfere constructively. Note that the phase of the reflection coefficient, with reference point at

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the center of an open electrode on 128° $LiNbO_3$, is $+\pi/2$. For the opposite direction, the phase difference between the generated and the reflected signals equals 5π, and they tend to cancel each other.

In a particular case simulated, the metallization thickness was taken to be 5% of h/λ. To minimize the reflectivity while maintaining a reasonable width of the electrodes, the metallization ratio was reduced from 0.5 to 0.4. The resulting reflectivity is on the order of 2% per wavelength. For the wide floating electrode, the metallization ratio corresponding to the maximum of reflectivity also occurs for $a/\lambda = a/(2p_0) = 0.4$, which approximately yields a reflectivity of 10% per electrode [12].

In addition to the structure of Fig. 1, a topology with groups of $\lambda/2$-spaced fundamental-mode floating electrodes used as the reflecting element may be envisaged. Then, within the unit cell, the reflector is placed such that the center of the floating electrode adjacent to the first transducer electrode coincides with Rc, i.e., the Rc-Ec distance equals $7/4p_0$. To avoid center-to-center distances between adjacent electrodes smaller than $\lambda/2$, critical transducer electrodes should be omitted. Consequently, in order to enable efficient transduction, the integer number of wavelengths occupied by one unit cell then should exceed 2. For example, a 3λ-long unit cell would include two floating reflector electrodes and three transducer electrodes, and a 4λ-long unit cell would consist of three floating reflector electrodes and four transducer electrodes. These and longer sections using a number of $\lambda/2$-spaced fundamental-mode floating electrodes as reflectors may be considered elements of a group-type SPUDT structure [6]. The use of $\lambda/4$-wide floating reflectors and more than two transducer electrodes in a SPUDT cell results in the increase of electromechanical coupling and reflectivity per wavelength.

The directivity of a SPUDT transducer consisting of nine SPUDT cells ($N_{cells} = 9$) was simulated using a numerical tool [13]. The result suggests that the geometry indicated in Fig. 1, with $a/\lambda_0 = b/p_0 = 0.4$, is close to the optimum.

We also have numerically studied the properties of a simple filter consisting of two identical SPUDT transducers with their forward directions toward each other. Each transducer contains nine SPUDT cells ($N_{cells/IDT}$) of Fig. 1. The aperture is 100 μm and the pitch $p_0 = 0.8$ μm. The simulated performance of a matched filter is shown in Fig. 2. The insertion loss is approximately 3 dB at the center frequency 2.415 MHz, and the 3 dB bandwidth is about 100 MHz. Attempts to reduce the losses to the absolute minimum were not made. The loss level is due to the finite directivity of the transducers.

III. Discussion

A novel SPUDT structure using $\lambda/4$ and wider electrodes is proposed. Its operation is based on the significant difference between the reflectivity of $\lambda/4$-wide shot-circuited electrodes and that of floating $\lambda/2$-wide electrodes on 128° $LiNbO_3$ [11], [12]. The SAW filters, tags, sensors, and other SAW devices using these unidirectional transducers, operating at 2.45 GHz, will have critical dimensions of about 0.4 μm, accessible for mass production with standard optical lithography.

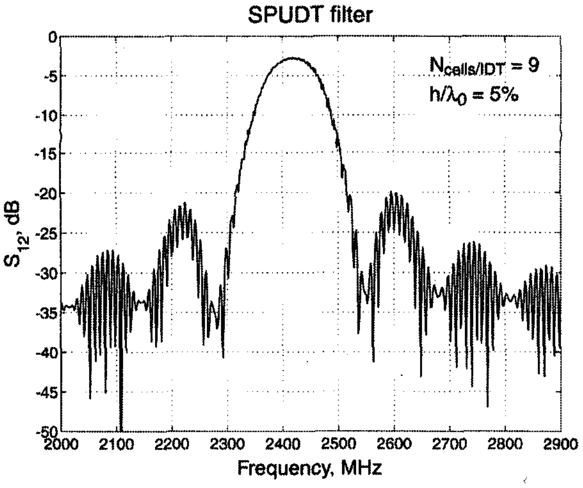

Fig. 2. Simulated frequency response of a SPUDT transversal filter. Here, $h/\lambda_0 = 5\%$ and for both transducers, $N_{cells/IDT} = 9$.

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